Zooplankton Composition and Abundance in Budd Inlet, Washington

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Introduction

Situated in southern Puget Sound, Budd Inlet is a narrow water body (roughly 2.5 x 11.5 km) with a north-south orientation (Figure 1). The inlet is well mixed in the winter and becomes stratified during the summer (WDOE 1997). The inlet is shallow, mostly less than 10 m deep. Tides are semi-diurnal with a range of 14.4 ft. The southern end of the inlet receives the majority of the fresh water entering the inlet and is home to most of the commercial activities in the inlet.

The growth experienced by the city of Olympia, Washington and surrounding communities has caused increased demand on existing wastewater treatment facilities. Increased disposal of waste water into Budd Inlet during the winter months has been proposed as a partial solution to this difficulty. A 13-month intensive field effort was made to determine the feasibility of this option. One tool that was created to help assist in this decision was a model that incorporated both water quality and circulation information. Because zooplankton make demands on and affect water quality, zooplankton sampling and analysis were included in the field portion of the Budd Inlet modeling study.

The circulation study, which was a major component of the overall investigation of Budd Inlet can be summarized, as follows (see Ebbesmeyer and Coomes 1998 for a comprehensive description of the circulation model): marine water enters the inlet along the western shore as a relatively dense, cold bottom layer. Fresh water leaves the inlet along the eastern shore as a lighter, warmer layer. These layers are well mixed during the winter months and become stratified in the summer. The central portion of the inlet contains a counterclockwise gyre that recirculates approximately 16% of the outgoing water back into incoming water. Flushing times for the inlet are short; the inner inlet flushes within one day, while the whole inlet does so within 10 days.

These processes in Budd Inlet may in part determine the structure of its zooplankton assemblages there. In order for zooplankton species to maintain viable populations in dynamic systems, reproductive rates must be equal to the export of individuals through death or transport (Ketchum 1954; Gupta et al. 1994) or they must have some other method by which to maintain critical densities (e.g., vertical migration to make use of stratified flows: Trinast 1975; Cronin and Forward 1979; Woolridge and Erasmus 1980; Cronin 1982; Hough and Naylor 1991, 1992; Morgan et al. 1997). Therefore, one question posed in this study is whether hydrographic phenomena in Budd Inlet (e.g., circulation patterns) are coincident with identifiable zooplankton assemblages or abundance patterns.

Because zooplankton investigations in Puget Sound and other Pacific Northwest estuaries are very rare, this study will also provide a basis for comparison to other coastal and estuarine data from the northeastern Pacific. It will also serve as a baseline of data for comparison with future zooplankton sampling in Puget Sound.

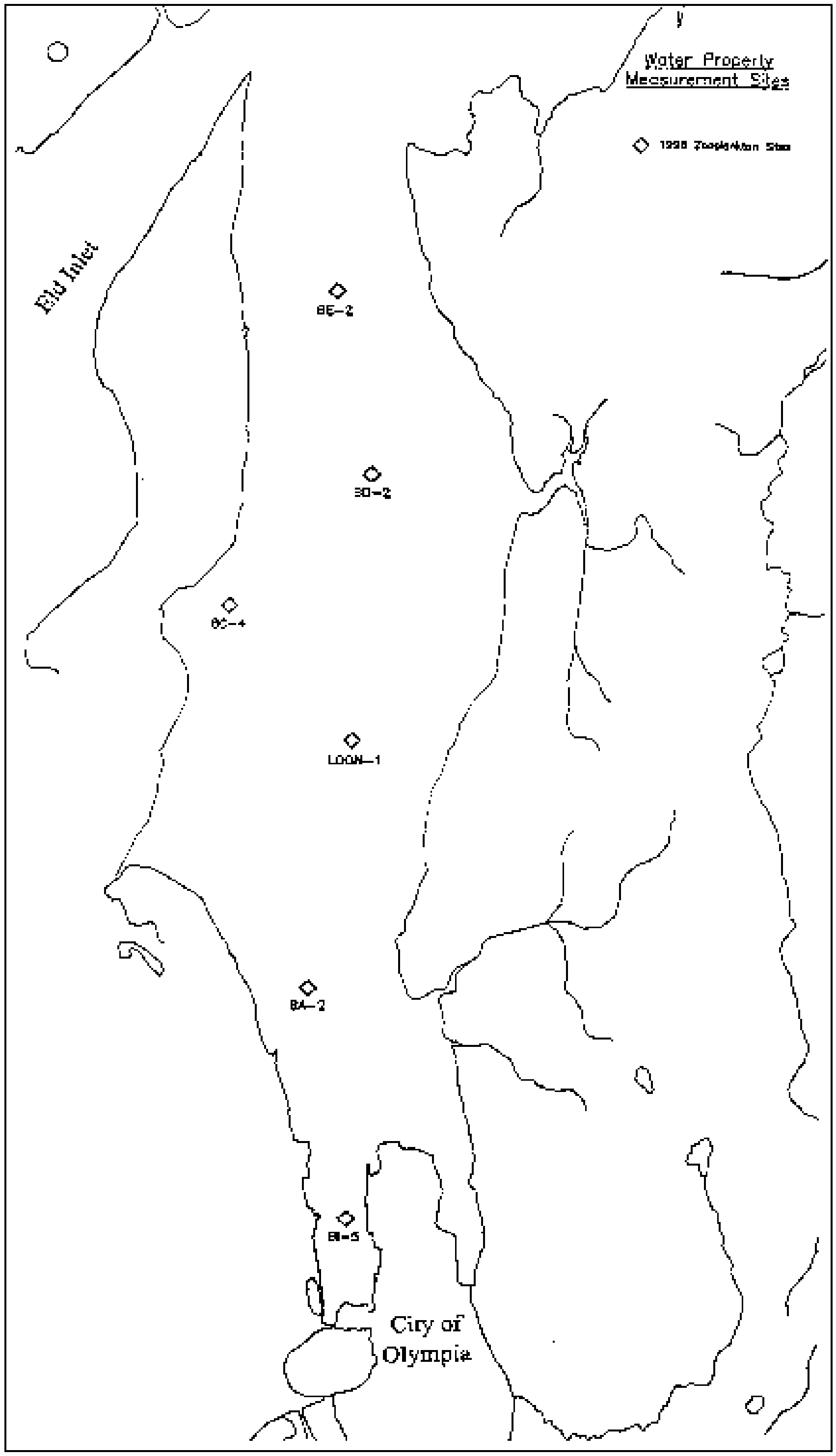

Figure 1. Budd Inlet, Puget Sound, Washington.

Methods

Zooplankton samples were taken approximately bimonthly for a total of 21 times within 12 months at six stations. The stations were arrayed roughly in a line starting in West Bay and continuing up the center of the inlet (Figure 1). The stations sampled were designated as follows: BI-5, BA-2, Loon-1, BC-4, BD-2, and BE-2. Samples were collected using a 0.5-m 220-µm mesh net, which was towed vertically through the water column by hand. Samples were fixed on board and had a final formaldehyde concentration of approximately 10% by volume. A Hensen's Stempelpipette was used for quantitative subsampling of the zooplankton fraction between 0.253 and 2 mm. Zooplankton larger than 2 mm were counted in their entirety, except on rare occasions (very numerous or split for biomass measurements before identification), in which case they were split with a Folsom plankton splitter. After taxonomic identification, each sample was dried for 24 hr at 60 _C and weighed to the nearest 0.001 g.

For other components of this study, the inlet was divided into three regions: inner, central, and outer. The inner inlet was defined as an area south of an east-west line drawn from Priest Point (Figure 1). Station BI-5 is located within this region and station BA-2 is located on its boundary. The central inlet encompasses the area from the BA transect to the BC transect; station Loon-1 is in this portion and station BC-4 lies on the boundary. The outer inlet contains station BD-2 and BE-2 and is defined as the area north of the BC transect to the inlet mouth.

Results

Stations within and on the boundaries of the central inlet (BA-2, Loon 1, BC-4) usually had the highest abundance levels (Figure 2). Loon-1, in the center of this area, consistently had the highest abundances, and had the largest peak of over 6.7 x 10^4 m^{-3} individuals in June (Figure 2). In relation to the central inlet stations, average abundance levels decreased toward both the inner inlet (5.3 x 10^2 individuals m^{-3} at BI-5) and outer inlet (3.7 x 10^2 individuals m^{-3} at BE-2) (Table 1). Average biomass levels were highest at station BA-2 (Table 1), but the highest single biomass measurement occurred at station BI-5 on 1 July (Figure 2). Peaks in taxa that were large in size, but low in relative abundance sometimes caused dissimilarity in abundance and biomass data. For example, the discrepancy between biomass and numbers at BI-5 on 1 July 1997 (Figure 2) was caused by an increase in cnidarians (Figure 3).

Table 1. Average total zooplankton abundance and biomass (dry weight) for stations sampled over a 12-month period in Budd Inlet, Washington.

Station	Location in Budd Inlet	Abundance (Individuals m^{-3})	Biomass (grams)
BE-2	**Outer**	3656	0.079
BD-2	Outer	5786	0.109
BC-4	Central	7527	0.081
Loon-1	Central	11898	0.105
BA-2	Central/Inner Border	9831	0.144
BI-5	Inner	5325	0.120

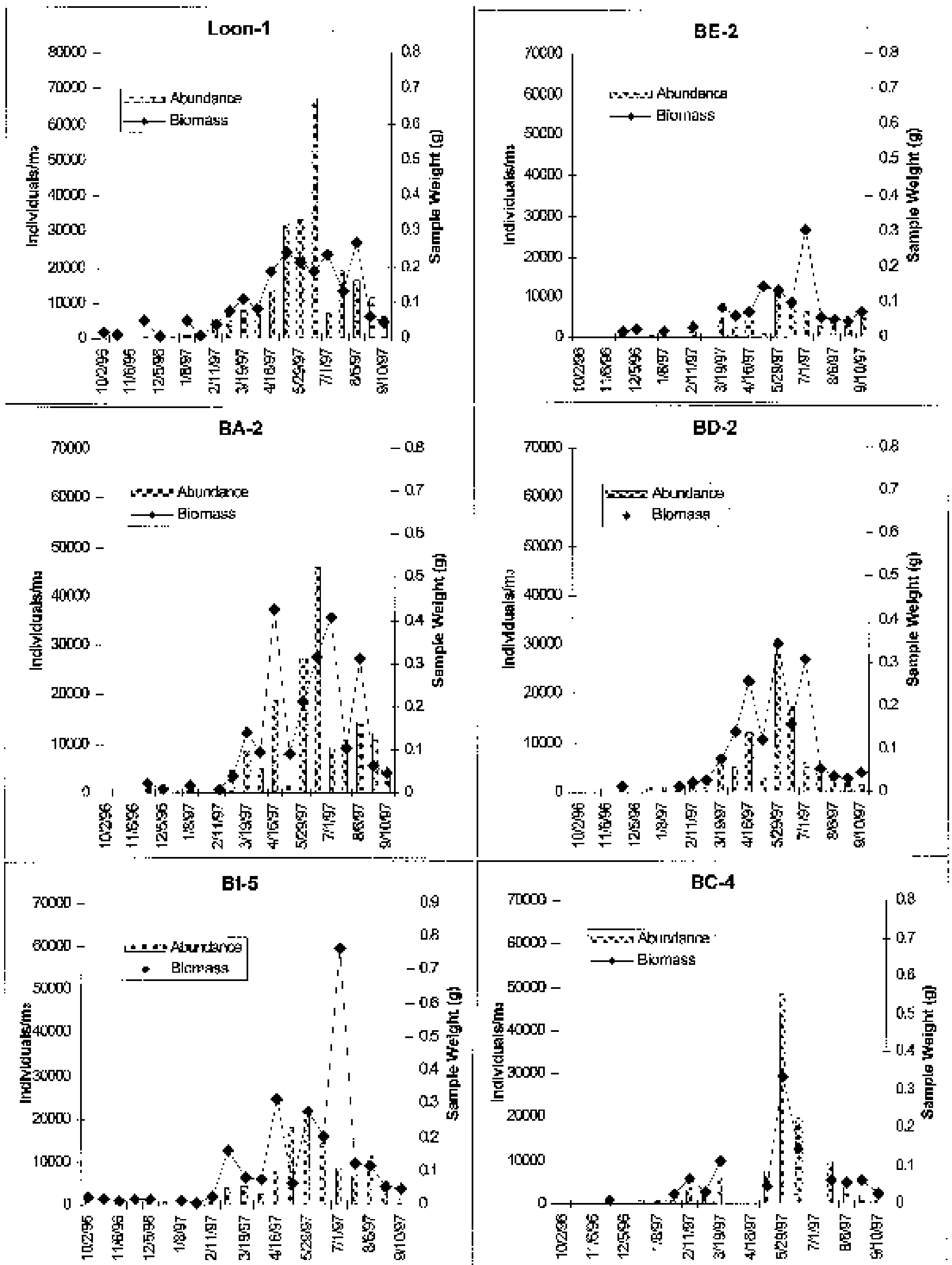

Figure 2. Zooplankton abundance and biomass in Budd Inlet, October 1996 through September 1997.

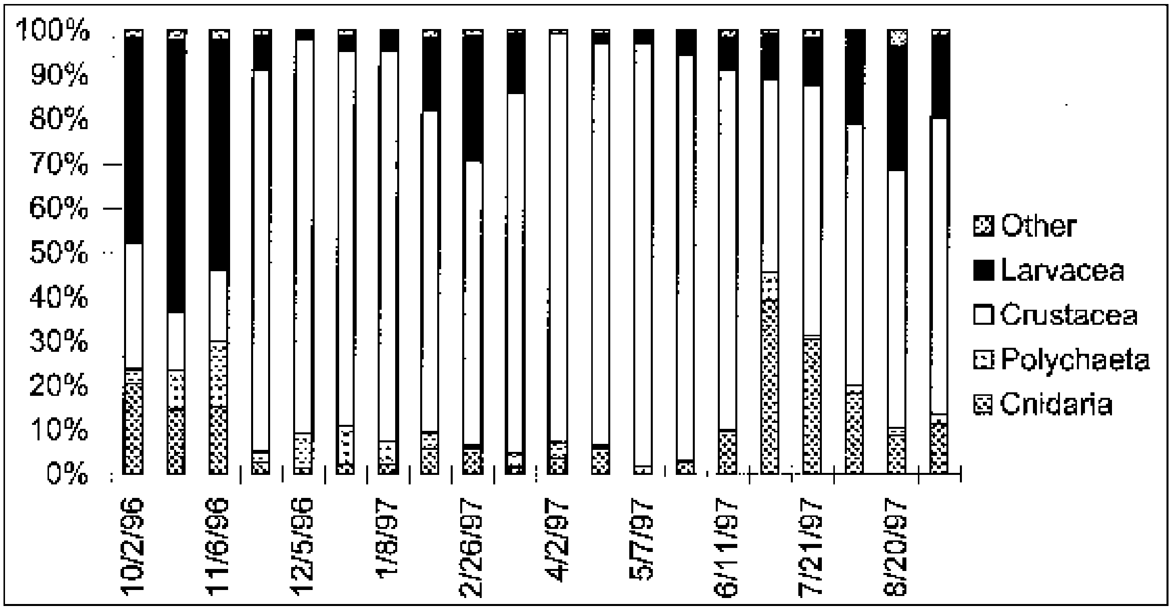

Figure 3. Zooplankton in inner Budd Inlet (station BI-5), October 1996 through September 1997.

Temporal variation played a larger role than spatial variation in determining zooplankton composition. At a relatively high level of taxonomic classification, crustaceans usually dominated zooplankton composition throughout the year (see Figure 3 for an example from one site). Other prominent groups included larvaceans, cnidarians, and polychaete annelid larvae (Figure 3). Larvaceans exhibited a distinct seasonality with large abundance peaks in Autumn 1996, when they were the numerically dominant group; smaller peaks occurred in February and August 1997 (Figure 3). In contrast, on a within-inlet basis, the general taxonomic composition of the zooplankton was usually similar on any given date (see Figure 4 for an example from one date).

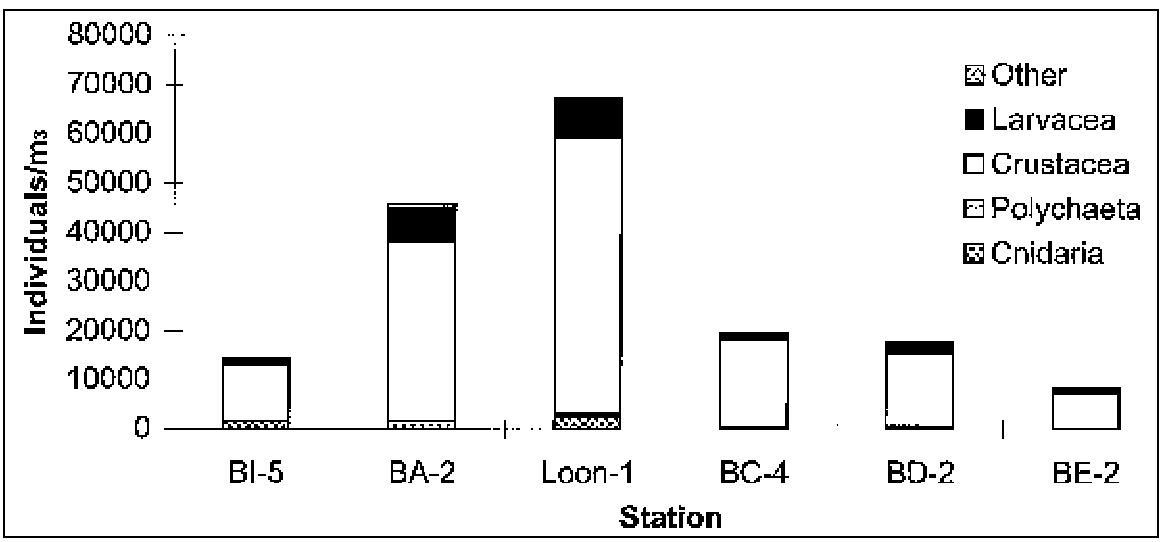

Figure 4. Zooplankton composition in Budd Inlet, 11 June 1997.

Of the crustaceans, calanoid copepods were usually numerically dominant (see Figure 5 for an example from one site). However, some taxa were seasonally abundant and exceeded or were similar to the numerical proportion represented by calanoids. These included planktonic larvae of barnacles and brachyuran and caridean decapod larvae in the spring and marine cladocerans (*Podon leuckarti* and *Evadne nordmann*) in the autumn (Figure 5). Of the calanoid copepods, the genus *Acartia* (subgenus *Acartiura*) was the most abundant in spring-early summer in all three regions of the inlet (see Figure 6 for examples from central, inner, and outer inlets). In late summer-early autumn, the numerically dominant calanoid was *Paracalanus* spp. In winter samples, numerical composition was more site-specific, with *Acartia* dominant in the inner inlet, *Paracalanus* spp. in the outer inlet (except in January, when *Pseudocalanus* spp. dominated), and a relatively even distribution of taxa in the central inlet (Figure 6).

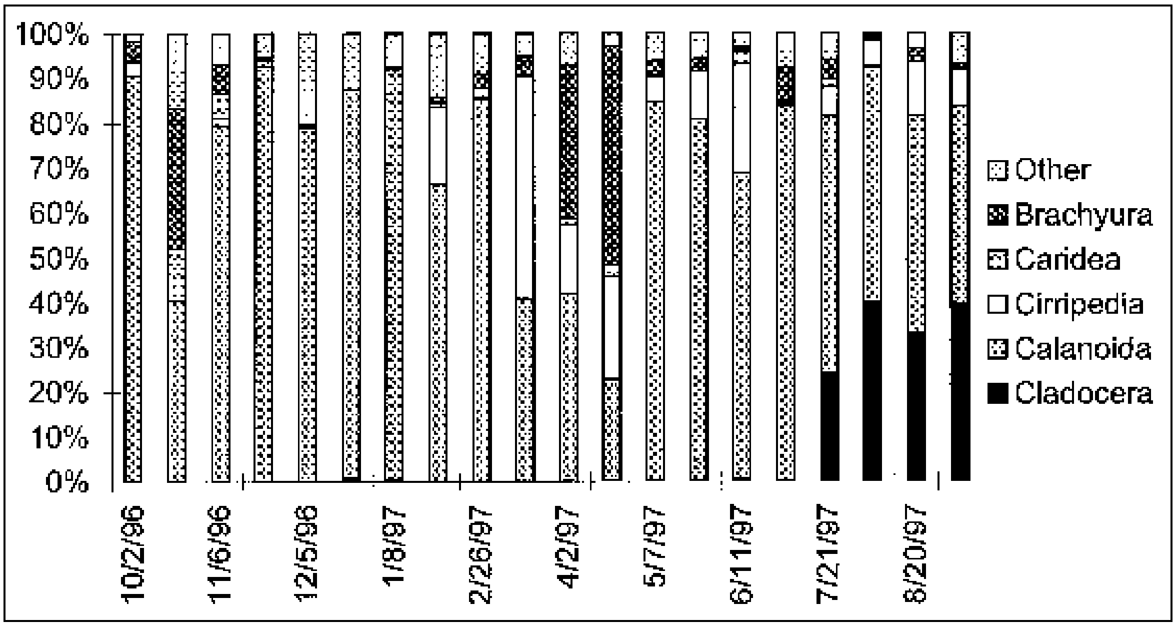

Figure 5. Crustacean composition in inner Budd Inlet (station BI-5), October 1996 through September 1997.

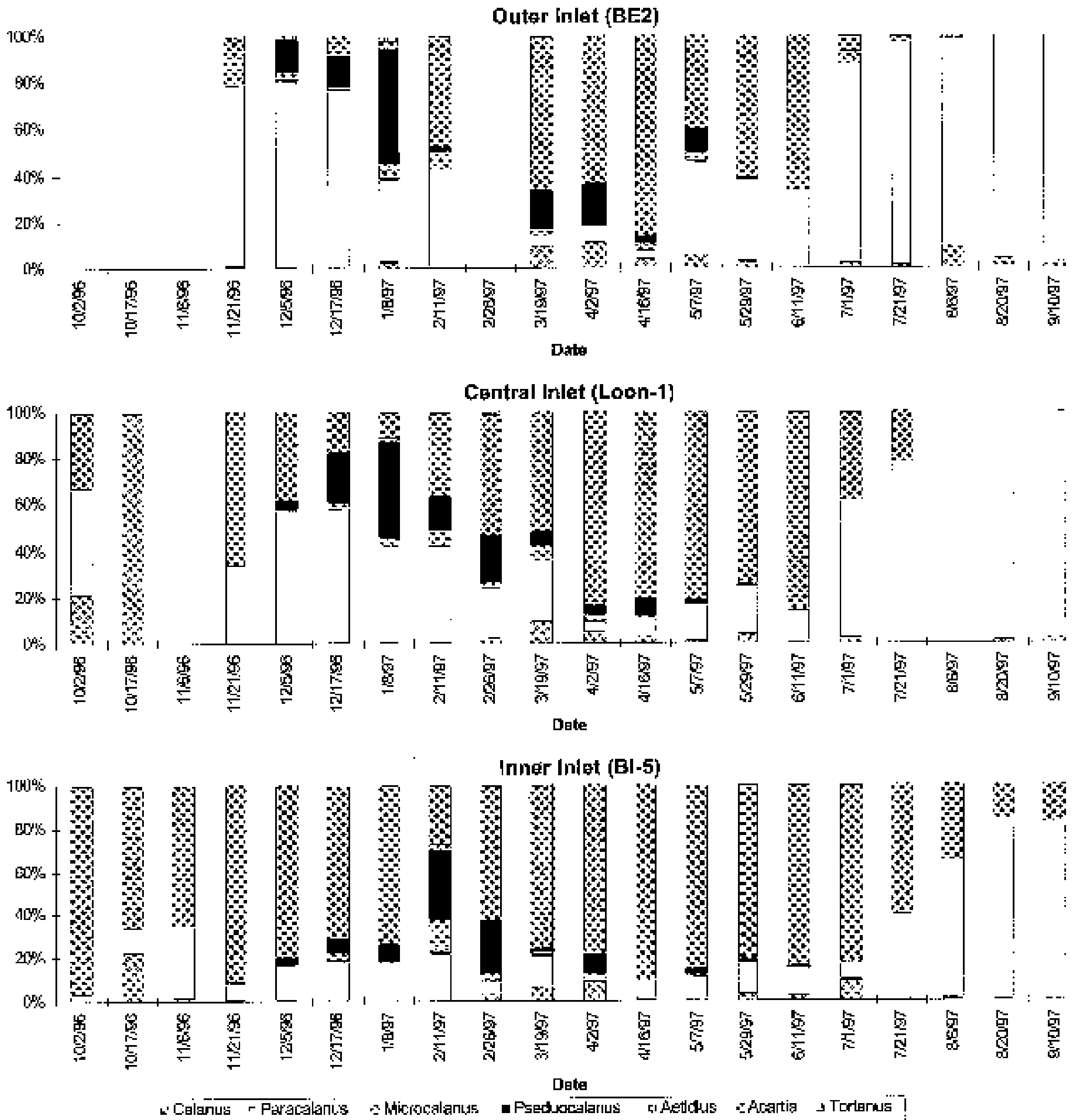

Figure 6. Calanoid copepod assemblages in Budd Inlet, October 1996 through September 1997.

Discussion

Prior to this study, we had hypothesized that the largest zooplankton abundance might occur in the inner inlet, based on previous studies showing high nutrient input into this region (WDOE 1997). However, our finding of highest zooplankton abundances in the central inlet agrees with the measured circulation patterns that showed relatively short (~1 day) flushing time in the inner inlet and a gyre in the central inlet (Ebbesmeyer and Coomes 1998). The combination of the zooplankton data and the circulation model suggests that the gyre increases retention of zooplankton in the central inlet.

Our finding that temporal variation was larger than within inlet variation is consistent with other studies of zooplankton in nearshore and estuarine systems (Minello and Matthews 1981; Sameoto 1975). These temporal and spatial variations have implications for growth and recruitment of important nearshore planktivorous fish such as Pacific herring, smelts, and juvenile salmon. For example, both *Paracalanus* and *Acartia* spp. have been found to be major prey items in the diets of these fish in both Puget Sound and coastal estuaries (J. Cordell, unpublished data; K. Fresh, Washington Department of Fish and Wildlife, unpublished data). In addition, planktonic prey (calanoid copepods, euphausiids, decapod larvae, and larvaceans) often dominated the diets of several species of Pacific salmon and their fish prey (Pacific herring, Pacific sand lance, and surf smelt) collected throughout Puget Sound (Fresh 1981; Fresh et al. 1979; Simenstad 1979). Therefore, both seasonal and longer-term (e.g., decadal) trends in Puget Sound zooplankton abundance may have implications for management of planktivorous fish and their predators (e.g., adult Pacific salmon). However, previous quantitative zooplankton studies of Puget Sound are rare, consisting of several unpublished student theses (Dempster 1938; Hebard 1956; Dumbauld 1985), and there are no past or current longer-term zooplankton monitoring programs in nearshore marine waters of the Pacific Northwest.

The zooplankton assemblages that we found in Budd Inlet had many taxa in common with those found elsewhere in Puget Sound and Hood Canal but had generally lower relative abundances of those species that dominated the deeper main basins of Puget Sound, Hood Canal, and the Strait of Juan de Fuca (Damkaer 1964; Chester et al. 1980; Dumbauld 1985; Bollens et al. in prep). In the dominance of shallow-water taxa such as *Acartia* (*Acartiura*) spp., *Paracalanus* sp., *Podon*, and *Evadne*, our data are similar to those from shallow basins of Puget Sound, San Francisco Bay, and numerous other shallow embayments on the Pacific coast (B. Frost, UW School of Oceanography, unpublished data; J. Cordell and S. Bollens, unpublished data; Trinast 1975; Miller 1983; Ambler et al 1985; Kimmerer et al. 1993). One difference between our results and these studies was the dominance of *Acartia* (*Acartiura*).

With the increasing effects on water quality due to rapid urbanization of the Puget Sound region (e.g., domestic sewage, nonpoint-source pollution), temporal changes in zooplankton abundance and assemblage structure might be expected, with following consequences for higher trophic levels. Given the potential importance of zooplankton as indicators of water quality and ecosystem function, we strongly recommend that future environmental monitoring of Puget Sound include a basic zooplankton component.

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